§60. ECCD Experiments Using 84 GHz and 77 GHz EC-Waves

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The current diffusion time (that is, L/R time where L denotes plasma inductance and R plasma resistance, respectively) of LHD plasmas is rather long, typically a few seconds. To evaluate plasma current precisely, it is necessary to perform long-pulse discharges in which the plasma current is well saturated. An example of such long-pulse ECCD experiment using an 84 GHz / CW gyrotron though the available power of it is rather low, 0.1 MW, is shown in Fig. 1. The magnetic configuration was R_{ax}=3.75 m and B_{ax}= 1.478 T. B_{ax} setting was slightly lowered from the second harmonic resonance field for the frequency of 84 GHz, 1.5 T, to achieve on-axis power deposition considering the effect of Doppler-shift in the case of oblique EC-wave beam injection. The plasma was generated with an 82.7 GHz / 220 kW / 300 ms pulse and then the plasma was sustained with an 84 GHz / 100 kW / 8 s pulse. Here the 100 kW power for ECCD was injected in right-hand circular polarization aiming at the magnetic axis. The parallel fraction of beam direction $N_{//}$ to the toroidal magnetic field was 0.27. After the plasma generation the plasma current I_p continuously increases for ~5 s and shows saturation at the end of the discharge. An exponential saturation fitting shown in Fig. 1 with a bold gray curve well represents the experimentally obtained I_p, and the fitting gives a saturation time-constant of 2.3 s for the discharge.

To clarify the $N_{//}$ dependence of EC-driven current, $N_{//}$ was varied keeping the pulse length at 8 s. As seen in Fig. 2, the total plasma current changes its direction according to the change of the sign of $N_{//}$, and the direction agrees with the prediction from the Fisch-Boozer theory in the case of the beam injection from low-field side. From this plot, it is known that the bootstrap current of these plasmas are supposed to be ~1 kA and that the EC-driven currents over 5 kA flow in both the co- and counter-directions.

ECCD by use of high-power, long-pulse 77 GHz gyrotron was also tried. The 77 GHz EC-wave injected with 2-O antenna at an outside horizontal port was used because a wide range of beam injection direction was available with this antenna. The 77 GHz / 1 MW / 600 ms pulses were applied from 2.65 s to after-glow plasmas. The counter-NB injected until 2.3 s sustains the plasmas (R_{ax}=3.75 m and B_{ax}= 1.393 T) and generates large current of about -20 kA. After the termination of counter-NB, $|I_p|$ decreases until the start of EC-wave injection. With small or excess $N_{//}$, the decrease in $|I_p|$ just stops while with $N_{//}$ of -0.38, $|I_p|$ lincreases again. Though the magnetic field setting in the experiment was not appropriate for 2nd harmonic ECCD by 77 GHz wave, significant EC-driven current of ~2 kA was observed. In the next experimental campaign, optimization of ECCD by 77 GHz wave will be performed.

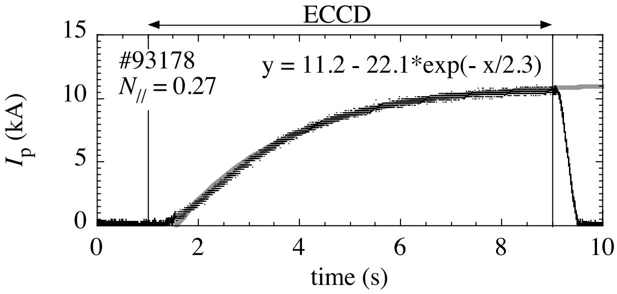

Fig. 1 A waveform of plasma current in a long-pulse ECCD discharge with the pulse length of 8 s.

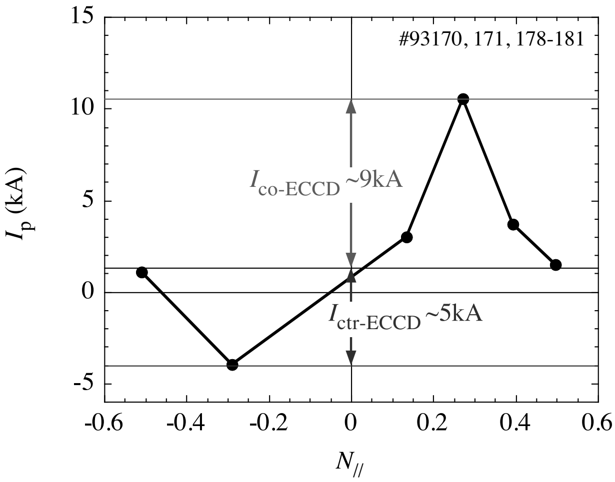

Fig. 2 Dependence of saturated plasma current on EC-wave beam direction $N_{//}$ obtained with 8 s discharges.

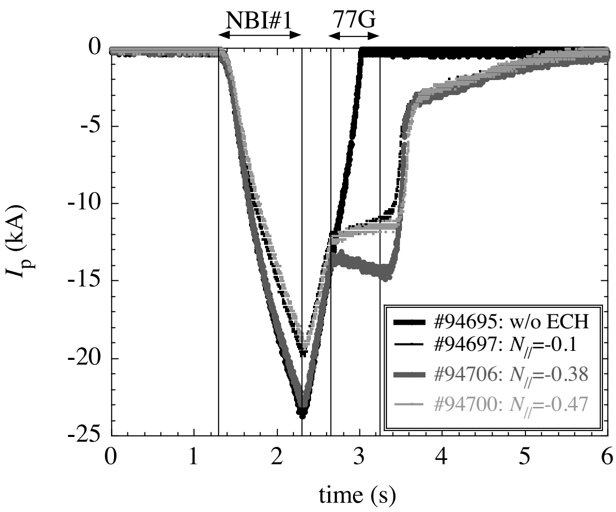

Fig. 3 Change of plasma current by application of high-power 77 GHz EC wave.